# RESTORATION OF BRINE WATER IMPACTED SOILS USING HALOPHYTES AND SOIL DISTURBANCES IN WEST TEXAS

A Thesis

Presented to the

Faculty of the College of Graduate Studies and Research

Angelo State University

For Partial Fulfillment of the

Requirements for the Degree

MASTER OF SCIENCE

by

KYE RONALD BURRIS

May 2017

Major: ANIMAL SCIENCE

RESTORATION OF BRINE WATER IMPACTED SOILS USING HALOPHYTES AND SOIL DISTURBANCES IN WEST TEXAS

By

KYE RONALD BURRIS

APPROVED

Dr. Cody B. Scott

Dr. James W. Ward

Mr. Corey J. Owens

Dr. Nicholas J. Negovetich

April 6, 2017

APPROVED:

Dr. Susan E. Keith
Dean, College of Graduate Studies and Research

## Acknowledgements

I would like to start off by sending my sincere gratitude for any and all of those who have helped me get where I am today. I would like to thank my committee consisting of Dr. Cody Scott, Dr. James Ward, Mr. Corey Owens, and Dr. Nicholas Negovetich for all of their time and effort input into this study. Thank you to fellow graduate students Chris Miller and Cody Riddle for all of the assistance throughout. Thank you to Michael Foust, Dillon Bagnall, and many other students in the Geology Department for the assistance in the completion of the project. I would like to also extend a special thanks the Agricultural Department faculty for their time instilled in me. I would especially like to thank my parents, Keith and Kristal Burris, and my family who has been there always. I could not have accomplished such feats in life without the consistent love and support from you all. Finally, thank you Haley for never wavering in your constant love and support.

## Abstract

Contamination from brine water alters soil chemistry and capability. This includes lower infiltration rates and a change in the amount of essential nutrients available for plant growth. This study took place on a 15.7 hectare “kill zone”. Six halophyte species were planted to evaluate their ability to grow and remediate salt at the site. The species in this study include Inland saltgrass (*Distichlis spicata*s), Alkali sacaton (*Sporobolus airoides*), Common and Giant Bermuda grass (*Cynodon dactylon*), Giant sacaton (*Sporobolus* wrightii), and Four-winged saltbush (*Atriplex canescens* Soil compaction exceeded 2068 kPa at the surface. Ripping and furrowing transects were established to improve soil structure. Alkali sacaton exhibited the lowest mortality rates. Four-winged saltbush produced the highest amount of biomass. Soil compaction was generally not affected my treatments or plant type. All species except for Inland saltgrass showed a moderate ability to survive.

## Table of Contents

Page

List of Tables ........................................................................................................ vi

List of Figures ....................................................................................................... vii

Introduction ...........................................................................................................1

Objectives ..............................................................................................................3

Literature Review ...................................................................................................4

Methods ..................................................................................................................7

Results ...................................................................................................................12

Discussion .............................................................................................................21

Future Research and Implications .........................................................................23

Literature Cited .....................................................................................................24

## List of Tables

Page

Table 1. Percent mortality rates of plant species ........................................................ 13

Table 2. Percent (%) mortality rates of plant species separated by treatment ......................... 14

Table 3. Percentage of sodium concentration in plant species ................................................ 17

Table 4. Soil compaction by depth ........................................................................................... 19

Table 5. Sodium levels (mg · $kg^{-1}$): Initial vs. end treatments ............................................... 20

## List of Figures

Page

Figure 1. Research site ........................................................................................................8

Figure 2. GIS Map of the planted plots on the research site ....................................................11

Figure 3. Plant species dry weight separated by treatment means (P < 0. 05).........................15

Figure 4. Soil compaction by plant species varied across treatments (P<0. 05)......................18

## INTRODUCTION

Thousands of hectares of rangeland and cropland are damaged every year because of the processes involved with oil and gas exploration. The main cause is the historical non-regulation of pumping brine water onto the soil. This leads to decreased forage, higher susceptibility to erosion, decreased grazing value, and the introduction of unwanted species of plants. Not only does it affect grazing land but also cropland as well. In Texas, 174,000 ha of land have been affected by saline contamination (McFarland et al. 1987). High salt content and drought are the two major causes of the reduction of crop yields worldwide (Boyer 1982). Some areas can experience even up to 50-80% crop loss, depending on the tolerant ability of the crop and level of contamination (Buchanan et al. 2000).

The focus of this project was on brine water spills from historic oilfield activity in most southern and western parts of Texas. The known method of reclaiming these soils is to flood the area with fresh, clean water to leach the salts out. However, this is not economically feasible or always effective. All too often, sites are abandoned after contamination because of the difficulty and cost of reclamation.  Thus, more practical means of reclamation are needed to produce an economic gain rather than to lose profit (Warnock 2003). A more practical method, first introduced in Pakistan by Chaudri et al. (1964), is using halophyte plants as a means to reclaim the soil.

---

Rangeland Ecology and Management

Halophytes are plants that can withstand high levels of salinity in soils. They can tolerate concentrations of salt that would normally kill 99% of other plants (Flowers and Colmer 2008). In addition, these plants decrease salinity in surrounding soils which results in increased plant growth and diversity of halophytes and glycophytes (plants with no salt tolerance)  (Ungar 1974). For a halophyte to be practical and produce an economic gain, they must be widely distributed, have the ability to accumulate high amounts of ions, possess the potential for high biomass production, and provide forage for livestock and wildlife (Warnock 2003).

## OBJECTIVES

1. Assess different species of grasses and shrubs for establishment in saline-contaminated soils
2. Determine most feasible method of re-vegetating saline-contaminated soils

## LITERATURE REVIEW

Most plants are unable to survive in high saline soils because of ion toxicity (Hasegawa et al. 1986). Halophytes have the unique ability to avoid this toxicity by accumulating these toxic saline ions in shoots (Flowers et al. 1977) and redistributing the excess ions to their leaves or alternate plant parts (Yeo and Flowers 1984). Alternatively, some halophytes secrete the salts into glands or bladders (Liphschitz and Waisel 1982).

Halophytes accumulate salts and increase soil quality, but in order to be a practical species, they must provide goods or services to achieve desired goals. Some halophytic species will block salt at the root cortex or root-soil interface. This is an avoidance method used by the plant but will ultimately defeat the purpose of bioaccumulation (Jeschke 1984; Warnock 2003). All halophytes have unique methods to avoid ion toxicity, but when it comes to grazing value and bioaccumulation, certain species are needed in order to properly dispose of salts while providing adequate nutrition for livestock. Ideal halophytes for reclamation would accumulate salts in leaves that could be consumed by livestock to reduce total salt concentrations on contaminated sites.

*Distichlis spicata* (L.) Greene (Inland saltgrass) is the most widespread, salt tolerant halophyte species. It has developed cultivars such as forage crops, turfgrass, and cereal crops (Aronson 1985; Gallagher 1985; Yensen 1985). This species can tolerate a wide range of soil types and salinity and thrives in saline desert areas. It can tolerate anywhere from 0. 03 - 5. 5% total salts and is the most common halophyte species in the United States. It is a rhizomatous, shallow rooted grass that can withstand high salinities while spreading along the ground (Ungar 1974). Inland saltgrass is known as a salt accumulator, meaning that it has excess glands on its leaves to store excess salt ions. They can be planted in the ground by seeding or cut rhizomes; however, additional soil moisture is required for the rhizomes to establish as compared to seeds (Pavlicek et al. 1977).

*Atriplex canescens* (Pursch) Nutt. (four-winged saltbush) is an evergreen shrub containing highly nutritious leaves and seeds that make it a preferred choice of forage for livestock and wildlife (Powell 1998). This species is also a salt accumulator as it has excess glands on its leaves for salt ions.  Seed germination for four-winged saltbush is ideal at levels of low salinity with moderate temperatures. Increased temperatures seem to affect the salt tolerance level negatively (Mikhiel et al. 1992). There is not an optimum salinity level know for germination; however, the best temperature is 15-18°C (Potter et al. 1986). This species can either be established from seeds or cuttings (Weisner and Johnson 1977). When planting four-winged saltbush alone, plant density plays a role in biomass production. The higher the density, the higher the quantity of biomass will be produced resulting in lower branch diameter. In addition, grazing needs to be monitored because complete defoliation results in plant loss (Benjamin et al. 1995).

*Sporabolus airoides* (Torr. ) Torr. (alkali sacaton) is another drought and salt tolerant species that provides forage for livestock and accumulates salts. It is native to Utah and is a large bunchgrass that provides excellent forage for livestock and wildlife. This species can survive on 30. 5-45. 7 cm of rain annually (Gould 1975) and has traditionally been used to reclaim sodic soils around oilfield sites and any other saline waste site. Because it is a large bunchgrass, it is also used to decrease soil erosion. This plant can be established by seeds or tillers and is usually more successful under soil disturbance (Gould 1975).

*Sporobolus wrightii* Munro ex. Scribn. (giant sacaton) is a larger version of alkali sacation. It is a large bunchgrass used to reclaim saline soils, and aid in prevention soil erosion. It is established through seeds and tillers and is typically more successful under soil disturbance (Gould 1975).

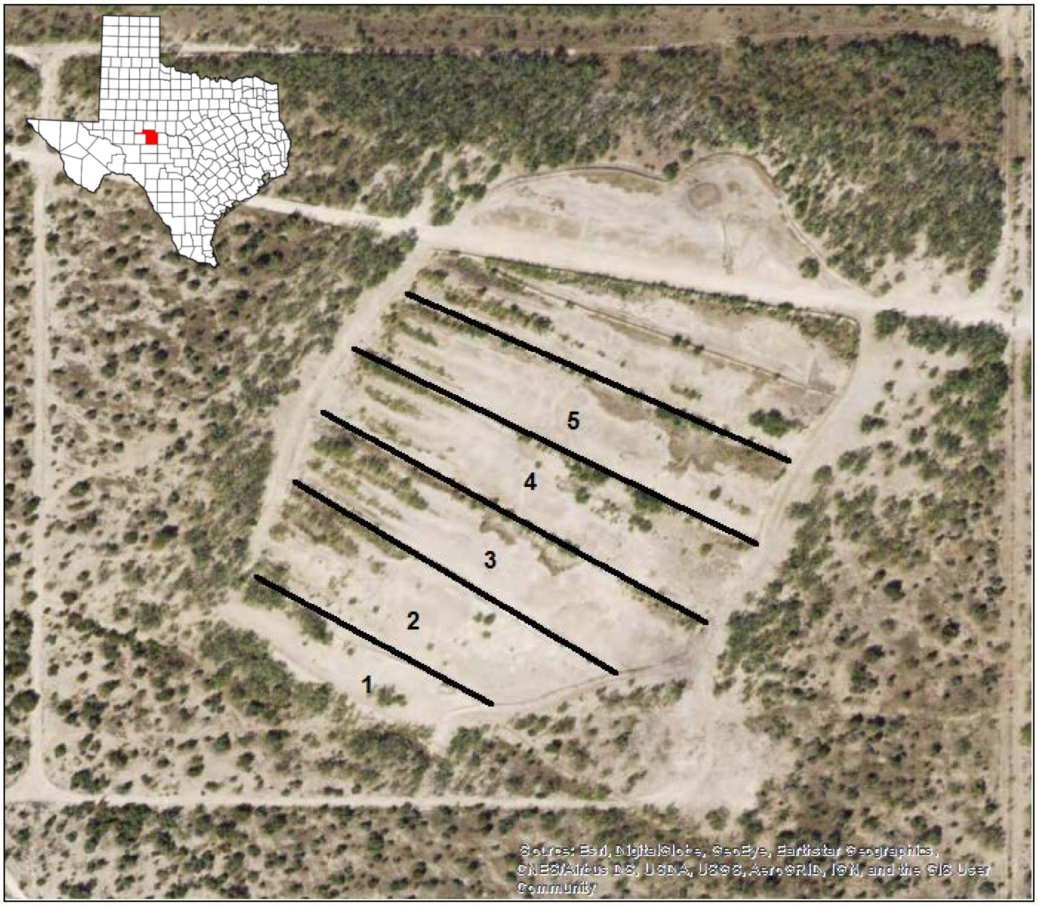
*Cynodon dactylon* (L.) Pers. (giant bermuda and common bermudagrass) are the last two species. These species can tolerate high amounts of salt in the soil but are not as drought hardy as the other species. Cold temperatures, usually under 12. 2°C, will cause discoloration and wilting. It normally has greater success in moderate temperatures with anywhere from 63. 5-25. 4 cm of rainfall (Gould 1975).  Either species can establish from rhizomes, stolons, or seeds. It has excellent grazing tolerance as well as excellent erosion prevention and can withstand a broad range of pH levels (5.0 - 8.5) (Gould 1975). The two species are the same except giant bermuda will grow taller than common bermudagrass due to slight genetic modifications. Other than size, they are the same plant.

## METHODS

The targeted site is approximately 12 km south of San Angelo, Texas (31. 284001 N, 100. 418085 W). It is a 5. 7 ha-plot with extremely high sodium levels (2902 mg · $kg^{-1}$ ) located on an old brine water spill site from the production of oil and gas. Under the surface, it is an alluvial rubble zone of Cretaceous cover over the older Permian impermeable clay rocks. The high concentrations of salts have caused the sodium ions in the soils to replace the calcium and magnesium ions in the process of cation exchange. These factors make it almost impossible for water or roots to penetration. Vegetation is only visible on lines running parallel to the site (Figure 1). These “lines” are berms that were established in the 1980s in an attempt to catch runoff to dilute and leach out salts. Thus, the only vegetation growing is on the up gradient of the berms, where years of rainwater have diluted some of the salts. The stock pond on the northeastern side of the site remains relatively unaffected. There is an active cow calf operation on the ranch as well as numerous species of wildlife.

After initial observation of the soil profile and the use of a soil compaction probe, it was determined that the soil at the beginning state is far too compact to provide for root penetration. Within 50.8 mm into the topsoil, the compaction is over 2,068 kpa. Plant roots of the selected species will not establish in any soil over 2,068 kpa.

The site is divided into five blocks, divided by the berms, with each block receiving two soil disturbance treatments along with a control (no soil disturbance). Both soil disturbances run parallel to the existing berms. One disturbance consists of ripping the soil,




Date: 4/13/2017
Coordinate System: GCS WGS 1984
Datum: WGS 1984
Units: Degree
Reference Scale: 1:0

Figure 1: Research site

45 cm deep with a single-shanked ripper. The second soil disturbance consists of furrowing the soil 45 cm deep with a single furrow. The divisions can be seen on Figure 1, with the first section starting at the bottom left and continuing in order until stopping at Section 5. Salinity levels decline from the highest concentration to the lowest on the site, moving from left to the right (Figure 1). The five halophyte species were planted at random locations along the two soil disturbances and along a transect in the control (no soil disturbance).

The six halophyte species selected were inland saltgrass, alkali sacaton, giant sacaton, four-winged saltbush, and two varieties of bermudagrass (giant and common bermuda). These grass and shrub species are also useful for grazing and browsing for livestock and deer, allowing for the desired final product of the disposal of biomass. The initial plant date for the eight and a half month study was March 15, 2016, making the end date October 31, 2016. Two hundred and twenty five plots were planted. Each species was planted nine times in each of the five sections; three times per treatment transect. The grass plots were a measured 0.3 $m^2$ quadrat seeded in disturbed soil for our two treatment methods, and planted in a lightly disturbed seed bed for the control. The four-winged saltbush plants were established seedlings grown for one month in the Angelo State University Management, Instruction, and Research Center greenhouse prior to planting. The different species were planted at random throughout each section and were marked with colored flags representing each species. The four-winged salt bush was caged with welded wire to prevent damage from natural browsers such as deer. GPS coordinates were taken at each plot and cage. The data was put into ArcGIS to provide a map (Figure 2) and detailed legend to easily access and update the data.

Two soil collection periods were recorded throughout the year of data collection. One was taken before planting and one was taken at the conclusion of growing season in October. One sample was taken at each of the established grass and shrub plots, and composited by species and section. The samples were marked and sent to Trace Analysis, Inc. to be tested for total sodium levels. Soil compaction samples were also taken at the end of growing season in all established plant plots in all transects. Plots were monitored by taking bi-monthly recordings of plant growth and establishment.

To avoid senescence of leaves and re-contamination of the soil, hand defoliation was used to simulate grazing. Plots were clipped in October, the end of the growing season. A 0.3-$m^2$ quadrat was placed in each stand of the established, herbaceous halophytes and clipped to ground level. Thirty percent of the four-winged saltbush leaves were hand-stripped to avoid inducing plant mortality. Harvested biomass was stored in paper bags, air-dried ($60^{o}C$ for 48 hours) weighed, and analyzed for total salt content. Recovery following defoliation will be monitored on subsequent years.

Data were analyzed using a randomized block design with sections of contamination as block. Differences among treatments were compared using repeated measures analysis with soil disturbance (rip, furrow, control) as the main effect, plant species as the subplot, and day of collection as the repeated measure. Means were separated using Tukey's Protected LSD when $P \leq 0.05$. Data were analyzed using the statistical package JMP (SAS 2007).

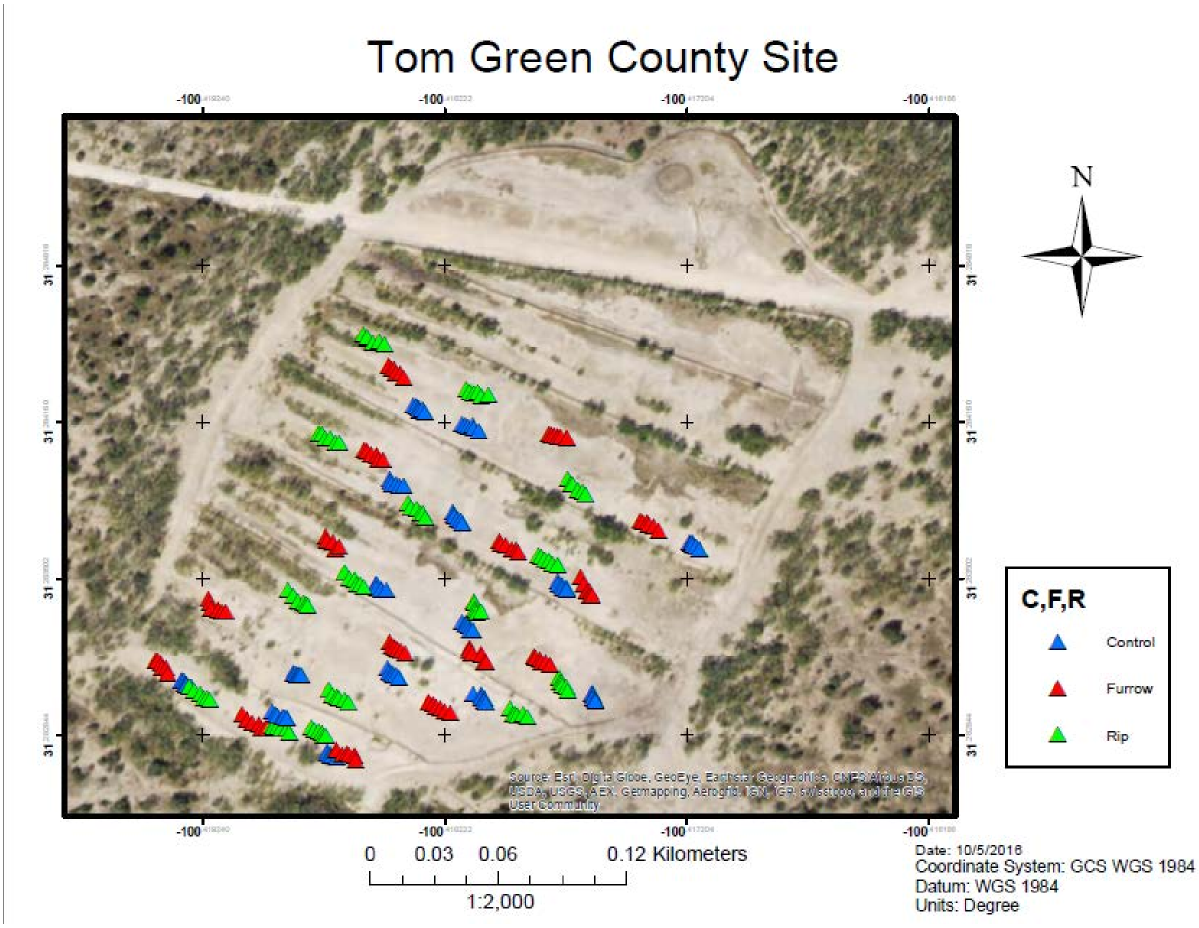



Figure 2: GIS Map of the planted plots on the research site.

## RESULTS

Alkali sacaton had the highest establishment rate ($P < 0.05$) while Inland saltgrass had the highest mortality rate (93%). Mortality rates for the other halophyte species are listed in Table 1. Mortality rates differed ($P = 0.06$) by treatment as well. The highest mortality rate of all species was in the control (i.e., no soil disturbance) (76.7% ± 8.9). Mortality rates were similar between ripping and furrowing (47.8% vs. 50.0%, SEM =8.9). Because mortality rates were calculated as a percentage of all replications, analysis of a treatment by species interaction is not possible because of a lack of degrees of freedom. However, it appears different species responded differently when compared across treatments (Table 2). Alkali sacaton had the lowest mortality rate in both treatments but not in the control, where giant sacaton and four-winged saltbush showed the best success. Inland saltgrass had the highest mortality rate in all treatments. Four-winged saltbush and giant sacaton showed the lowest mortality rates in the control treatment.  Common and giant bermuda and inland saltgrass showed the highest mortality rates in the control. Inland saltgrass was unable to establish under any condition on this site.

In the control, four-winged saltbush produced more biomass ($P< 0.05$) (Figure 3). For the furrow treatment, alkali sacaton, giant sacaton, and four-winged saltbush all had comparable biomass that was greater than the biomass of other species. Finally, four-winged saltbush showed the highest biomass in the rip plots.

Table 1: Percent mortality rates of plant species.

| Plant Species | Mortality (%) |
|---|---|
| Alkali sacaton | 37.8 ± 10.8 |
| Giant sacaton | 48.9 ± 10.8 |
| Common Bermuda | 57.8 ± 10.8 |
| Giant Bermuda | 66.6 ± 10.8 |
| Inland saltgrass | 93.3 ± 10.8 |
| Four-winged saltbush | 44.4 ± 10.8 |

Table 2: Percent (%) mortality rates of plant species separated by treatments.

| **Plant Species** | **Treatment Percent Mortality** | | |
|---|---|---|---|
| | **Rip** | **Furrow** | **Control** |
| Alkali sacaton | 13 | 33 | 67 |
| Giant sacaton | 47 | 40 | 60 |
| Common Bermuda | 60 | 33 | 80 |
| Giant Bermuda | 53 | 53 | 93 |
| Inland saltgrass | 93 | 87 | 100 |
| Four-winged saltbush | 33 | 40 | 60 |

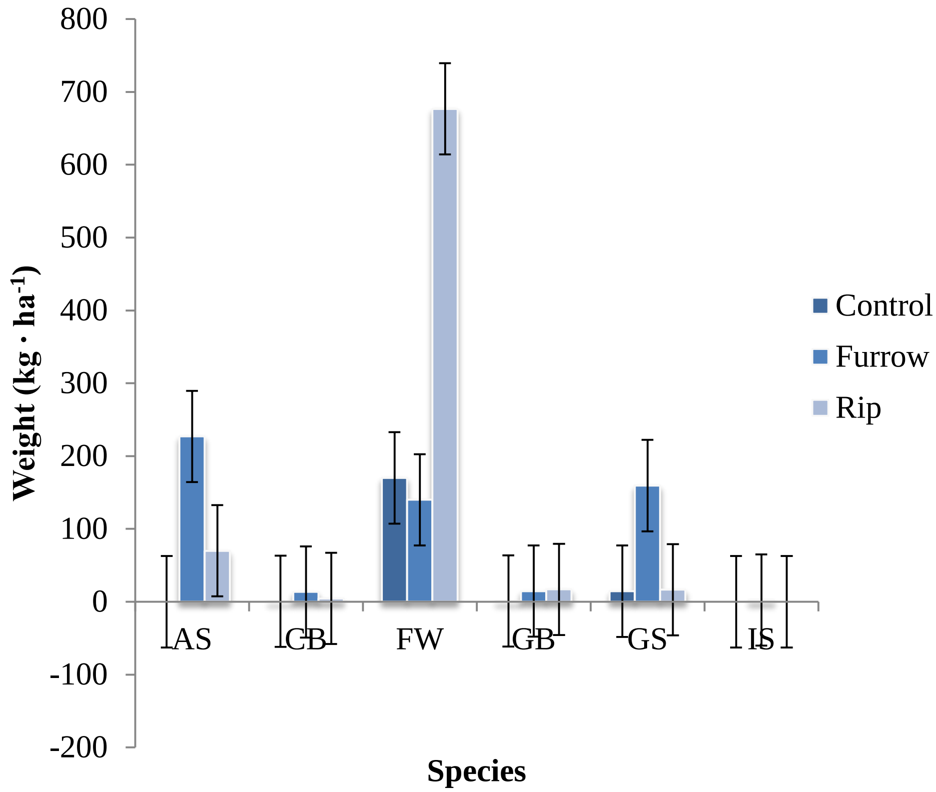



Figure 3: Plant species dry weight separated by treatment means (P < 0. 05).

The total salt content for the plants by species is shown below in Table 3. The three species listed were the only plant species with enough above-ground biomass for comparison of sodium concentrations. Alkali sacaton exhibited the highest sodium concentration in both of the ripped and furrowed soil disturbances. Sodium accumulation was similar between giant sacaton and four-winged saltbush irrespective of soil disturbance. Regardless of species, there is a trend toward no soil disturbance resulting in the lowest levels of sodium accumulation.

The soil compaction data was run by treatment (rip, furrow, control), plant species (Fig. 4), and depth (surface, 7.6 cm, 15.2 cm). Degree of compaction (kPa) was lower ($P < 0.05$) after ripping and furrowing. When separated by plant species, soil compaction was lower in the disturbance plots for all plant species except four-winged saltbush and giant bermuda. Four-winged saltbush was similar in the furrow plot while giant bermuda was similar in the rip plot to the control plots. Compaction differed by soil depth. Compaction measurements at the surface were significantly lower than those taken deeper in the profile (7.6 cm, 15.2 cm).

All established plant species in each treatment decreased sodium levels in the soil. Alkali sacaton showed the greatest remediation capabilities in the furrow treatment, while giant sacaton showed the most success in the rip treatment. Four-winged saltbush had the most success of the three in the control plots.

Table 3: Percentage of sodium concentration in plant species

| **Species** | **Treatment (Na %)** | | |
|---|---|---|---|
| | Rip | Furrow | Control |
| Alkali sacaton | 0.463 | 0.637 | 0.318 |
| Giant sacaton | 0.291 | 0.440 | 0.229 |
| Four-winged saltbush | 0.243 | 0.371 | 0.215 |

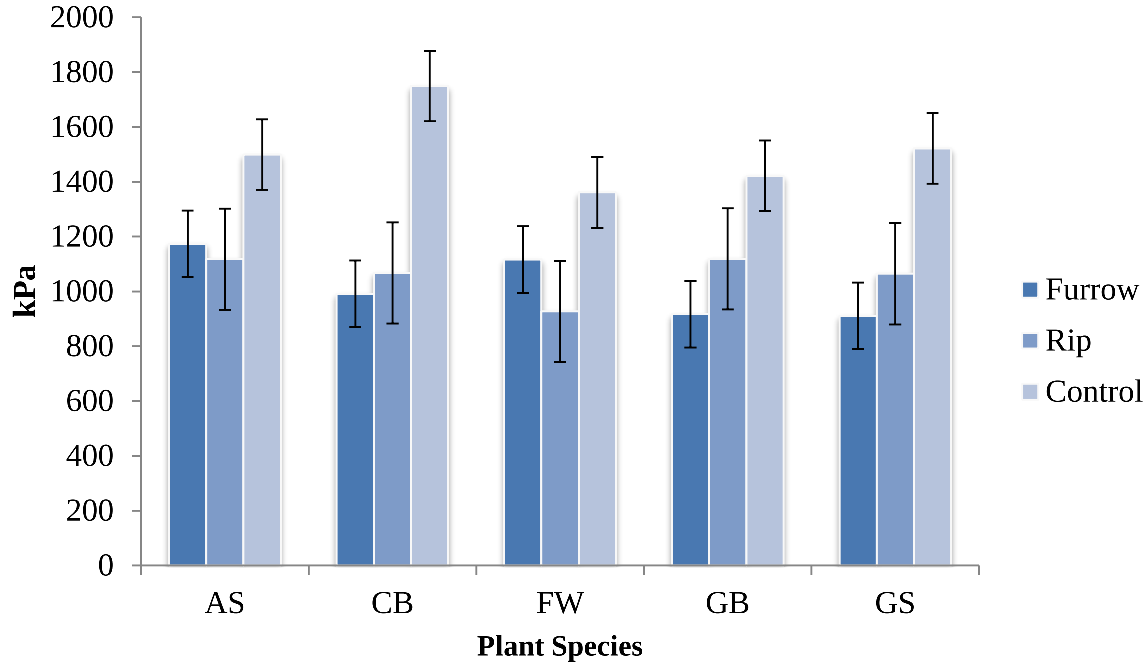



Figure 4: Soil compaction by plant species varied across treatments (P<0. 05).

Table 4: Soil compaction by depth

| Depth (cm) | Soil compaction |
| --- | --- |
| 0 | 568.00 |
| 7.6 | 1481.69 |
| 15.2 | 1553.99 |

Table 5: Sodium levels (mg · kg$^{-1}$): Initial vs. end treatments

| | **Soil Sodium Levels (mg · kg$^{-1}$)** | | | |
|---|---|---|---|---|
| **Species** | **Initial** | **Rip** | **Furrow** | **Control** |
| Alkali sacaton | 2902 | 1320 | 824 | 1190 |
| Giant sacaton | 2902 | 1120 | 850 | 2190 |
| Four-winged saltbush | 2902 | 1560 | 1540 | 842 |

## Discussion

The two types of soil disturbances, ripping and furrowing, impacted plant weight and success to varying degrees dependent on species. Alkali sacaton, giant sacaton, and four-winged saltbush all established relatively well when furrowing was applied. Four-winged saltbush also established well when ripping was applied. Four-winged saltbush showed the capability to produce more biomass under these arid, saline conditions. Regardless of soil disturbance, alkali sacaton successfully established and sustained plant vigor. It can also be noted that all of the plant species, excluding inland saltgrass, were moderately successful regardless of the soil disturbance. Alkali sacaton also exhibited the highest sodium concentration in the above-ground biomass. Therefore, it is the most successful grass in salt uptake from the soil. Soil compaction did appear to affect plant growth. There was also a trend toward species accumulating more sodium when the soil was disturbed.

Ripping and furrowing are common rangeland practices to improve soil structure, water infiltration, root penetration, and ultimately plant establishment. In this study, soil disturbance significantly reduced the level of soil compaction. The soil on the site is high in kaolinite clays, which form 1:1 layers of silicon and aluminum ions tightly bound together. This results in little water infiltration, poor aeration, poor root penetration, and soils that appear compacted. The chosen soil disturbance methods aided in the reduction of packed colloids on this site. In addition, in other clay-dominated soils, such as those high in smectite and vermiculate clays, ripping and furrowing may also be beneficial to improve infiltration. Once soil structure is re-established through soil disturbances like furrowing and ripping, water infiltration should improve, resulting in leaching of salts from the soil regardless of the type of clay.

For improvement of soil quality on the site, plant establishment is essential. It appears that planting alkali sacaton and four-winged saltbush provides the greatest opportunity for plant establishment and accumulation of salts. Once plants are established in a large enough density, livestock grazing at the end of the growing season could be used to remove above ground vegetation and accumulated salts. Grazing at the end of the growing season is recommended because plants have completed their growth cycle and grazing does little to reduce the longevity of plants when grazed at this time (Briske 1991).

Plots will continue to be monitored over the next several years. Continued establishment should improve infiltration rates and reduce soil salinity. This will introduce more organic matter, leading to acceleration in sodium leaching and a decrease in the exchangeable sodium percentage and electrical conductivity. That improvement aids in increasing water infiltration, water-holding capacity, and aggregate stability (El-Shakweer et al. 1998).

## Future Research and Implications

Future efforts should investigate the benefits of introducing organic matter, along with the already implemented techniques of halophyte plants in disturbed soil. Organic matter should aid in the leaching of sodium ions, prevention of the binding of soil ions, increased infiltration and permeability, and improved soil enzymatic and microbial properties (El-Shakweer et al. 1998; Blagodatsky and Richter 1998; Liang et al. 2003). For example, Tejada et al. (2006) found that cotton gin compost improved soil structure and stability. It improved the physical, chemical, and biological properties of the soil as well. Thus, the addition of cotton gin compost may further aid in the improvement in infiltration and plant establishment. Other remediation methods such as chemical and the use of microorganisms are likely less feasible due to water availability and expense.

## LITERATURE CITED


Aronson, J. A. 1985. Economic halophytes - a global review, p. 177-188 *In* G. E. Wickens, J. R. Goodin, D. V. Field (ed. ) Plants for arid lands: proceedings of the Kew international conference on economic plants for arid lands. George, Allen, and Unwin, London.

Benjamin, R. W., Y. Lavie, M. Forti, D. Barkai, R. Yonatan, and Y. Hefetz. 1995. Annual regrowth and edible biomass of two species of *Atriplex* and of *Cassia sturtii* after browsing. *Journal of Arid Environments* 29:63-84.

Blagodatsky, S.A., Richter, O., 1998. Microbial growth in soil and nitrogen turnover: a theoretical model considering the activity state of microorganisms. Soil Biology & Biochemistry 30, 1743–1755.

Boyer, J. S. 1982. Plant productivity and environment. *Science* 218:443-448.

Briske, D.D. 1991. Developmental Morphology and Physiology of Grasses. Grazing Management: an ecological perspective. Timber Press, Portland. p. 85-108

Buchanan, B. B., W. Gruissem and R. L. Jones (2000). Biochemistry and molecular biology of plants. American Society of Plant Physiologists. Rockville, USA. 1160

Chaudri. I. I., B. H. Shah, N. Naqvi, and I. A. Mallick. 1964. Investigations on the role of *Suaeda fruticosa* in the reclamation of saline and alkaline soils in the west Pakistan plains. *Plant Soil* 21:1 -7.

El-Shakweer, M.H.A., El-Sayad, E.A., Ejes, M.S.A., 1998. Soil and plant analysis as a guide for interpretation of the improvement efficiency of organic conditioners added to different soils in Egypt. *Communications in Soil Science and Plant Analysis* 29:2067–2088.

Flowers, T. J., P. F. Troke, and A. R. Yeo. 1977. The mechanism of salt tolerance in halophytes. *Annual Review of Plant Physiology* 28:89–121.

Flowers, Timothy, J., and T. Colmer. , 2008, Salinity tolerance in halophytes*, In *New Phytologist: Tansley Review,* p. 946, 2008

Gallagher, J. L. 1985. Halophytic crops for cultivation at seawater salinity. *Plant Soil* 89:323-336.

Gould, Frank W. 1975. The Grasses of Texas. Texas A&M University Press, College Station, Texas.

Hasegawa, P. M., R. A. Bressan, and A. K. Handa. 1986. Cellular mechanisms of salinity tolerance. *Hort Science* 21:1317–1324.

Jeschke, W. D. 1984. K+–Na+ exchange at cellular membranes, intracellular compartmentation of cations, and salt tolerance, p. 37–66. In: R. C. Staples and G. H. Toenniessen (eds. ). Salinity tolerance in plants. Wiley, N. Y.

Liang, Y.C., Yang, Y.F., Yang, C.G., Shen, Q.Q., Zhou, J.M., Yang, L.Z., 2003. Soil enzymatic activity and growth of rice and barley as influenced by organic matter in an anthropogenic soil. *Geoderma* 115:149–160.

Liphschitz, N. and Y. Waisel. 1982. Adaptation of plants to saline environments: salt excretion and glandular structure, p. 197–214. In: D. N. Sen and K. S. Rajpurohit (eds. ). Contributions to the ecology of halophytes. Dr. W. Junk Pub., The Hague. The Netherlands.

McFarland, M. L., D. N. Ueckert, and S. Hartmann. 1987. Revegetation of oil well reserve pits in West Texas. *Journal of Range Management* 40:122-127.

Mikhiel, G. S., S. E. Meyer, and R. L. Pendleton. 1992. Variation in germination response to temperature and salinity in shrubby *Atriplex* species. *Journal of Arid Environments* 22:39-49.

Pavlicek, K. A., G. V. Johnson, and E. F. Aldon. 1977. Vegetative propagation of desert saltgrass rhizomes. *Journal of Range Management* 30:377-380.

Potter, R. L., D. N. Ueckert, J. L. Petersen, and M. L. McFarland. 1986. Germination of fourwing saltbush seeds: Interaction between temperature, osmotic potential, and pH. *Journal of Range Management* 39:43-46.

Powell, A . M . 1998. Trees and shrubs of the Trans-Pecos and adjacent areas. University of Texas Press, Austin.

Tejada, M., C. Garcia, J.L. Gonzales, and M.T. Hernandez. 2006. Use of organic amendment as a strategy for salin soil remediation: Influence on the physical, chemical and biological properties of soil. *Soil Biology & Biochemistry* 38:1413-1421.

Ungar, I. A. 1974. Inland halophytes of the United States, p. 235-305. *In* R. J. Reimold and W. H. Queen (eds. ) Ecology of halophytes. Academic Press, London.

Warnock, Bonnie, J. 2003. Bioaccumulation of Salts by Halophytes as a Means of Reclaiming Saline Soils, p. 1-14, UMI Microform Inc. Ann Arbor, MI.

Weisner, L. E., and W. J. Johnson. 1977. Fourwing saltbush *(Atriplex canescens*) propagation techniques. *Journal of Range Management* 30:154-156.

Yensen, N. P., S. B. Yensen, and C. W. Weber. 1985. A review of *Distichlis* spp. For production and nutritional values, p. 809-822. *In* E. E. Whitehead, C. F Hutchinson, B. N. Timmerman, and R. G Vardy (ed. ) Arid lands today and tomorrow. Westview Press, Boulder, CO.

Yeo, A. R. and T. J. Flowers. 1984. Mechanisms of salinity resistance in rice and their role as physiological criteria in plant breeding, p. 151–171. In: R. C. Staples and G. H. Toenniessen (eds. ). Salinity tolerance in plants. Wiley, N. Y.